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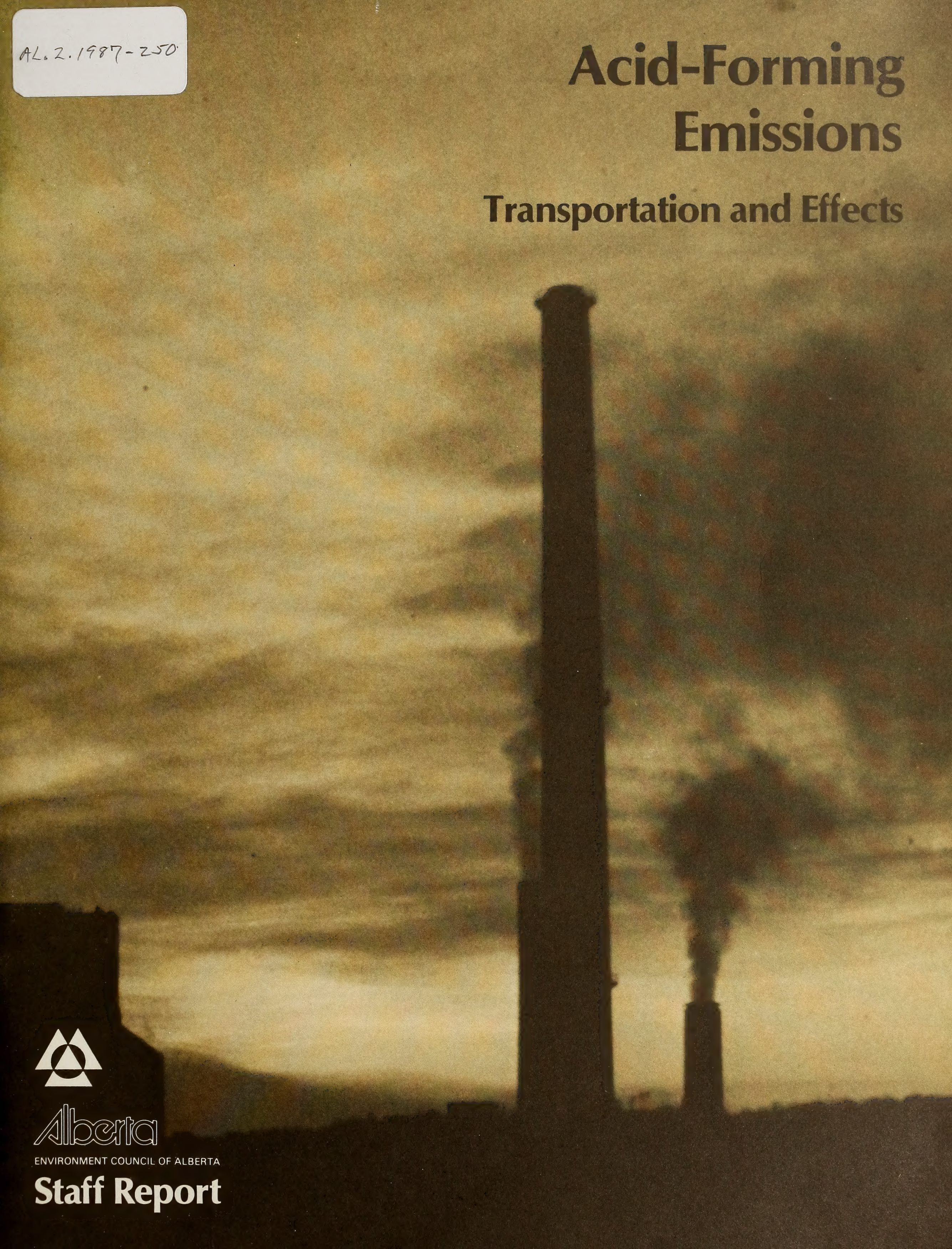
Acid-Forming Emissions

Transportation and Effects



Alberta

ENVIRONMENT COUNCIL OF ALBERTA

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Acid-Forming Emissions

Transportation and Effects

March 1984

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Environment Council of Alberta

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Preface

Considerable scientific and technical data have been gathered on the subject of acid-forming emissions and acid deposition. Much of this information, although publicly available, was not written with the general public as the intended audience. Consequently, those people who might wish to directly assess this rather high-profile environmental issue could find themselves having to read reports which require a knowledge of several areas of science in order to be understood. This report is intended to help the general public, particularly those people without a scientific background, to better understand the "acid rain" controversy by providing background information and summarizing a variety of relevant scientific literature. This report is not intended as a scientific treatise on the subject; a reading list is appended for those readers desiring more detailed information. The reading list, which does not purport to be complete, is organized by subject. A glossary is also included and contains those terms appearing in bold type in the text.

This report looks first at the relationship between the hydrologic cycle and air pollution, then considers the long range transport phenomenon in more detail. Alberta's position concerning both long range and short range transport is examined, but for the most part, this report is a general discussion, with references to data from other provinces and countries. Because long range transport is frequently a transboundary event, one chapter considers the jurisdictional aspects and implications of emission control and environmental effects. The report concludes with a look at various areas of research into long range transport and acid-forming emissions and some of the problems faced by researchers.

The preparation of this report was greatly facilitated by the competent and efficient assistance of the Environment Council's library, secretarial, and editorial staff. Considerable effort was expended by these people in the gathering of research material and preparation of the manuscript, and the author gratefully acknowledges their support.

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1.

Introduction

Two basic requirements for the survival of life on our planet are air and water. Not only is the quantity of these items important, but so is the quality, and ensuring that both of these criteria are met is becoming increasingly difficult in many parts of the world. The nature of these two resources contributes to this difficulty. Both are subject to the physical laws of nature in so far as their movements are concerned, and consequently neither respects political boundaries. Both have also been taken for granted and, frequently, little thought was given to the downstream or downwind effects of upstream or upwind activities. These considerations form the background against which certain atmospheric, chemical, and biological interactions are discussed in this report.

Although this report is intended primarily to be an examination of the long range transport of air pollutants, water and the hydrologic cycle are important aspects of this phenomenon. Parts of the hydrologic cycle coincide with stages in long range transport and when long range transport results in acid precipitation, aquatic systems can be among the most vulnerable. Concern to date has centred mainly around the long range transport of acid-forming emissions, that is, oxides of sulphur and nitrogen. Other atmospheric emissions can also be transported, and the presence of some of these (such as ozone) can affect the behavior of acid-forming emissions. However, discussion in this report will focus on emissions of sulphur dioxide and oxides of nitrogen.

In North America, public perceptions of the "acid rain" issue have been shaped to a large extent by accounts of the situation in the eastern half of the continent. Admittedly, the acid deposition problems in eastern Canada are serious and Canadian concern about the acidification of lakes and soils in sensitive areas of Ontario, Quebec, and the Maritimes is justified. However, the environmental and jurisdictional aspects in most of western Canada are different, and one of the objects of this report is to point out these differences and their significance, particularly with regard to the circumstances in Alberta.

Alberta does not currently generate or receive significant quantities of acid-forming emissions which are transported across either provincial or national boundaries — our acid-forming emissions are our own. This should make the control of emissions a much easier task since effectively only one political jurisdiction is involved; this contrasts with the situation in eastern Canada where many of the acid-forming emissions originate outside the province which suffers the eventual damage. Furthermore, the predominance of **calcareous** bedrock formations in Alberta means that most of our soils and lakes are well buffered and thus are naturally protected against acid deposition. The only area lacking this protection is a relatively small portion of northeastern Alberta, on the pre-Cambrian shield.

All of this is not to say that Alberta has no problems due to acid-forming emissions. Concern here has tended to focus more on the direct health and environmental effects of sulphur dioxide (SO_2) emissions rather than on acid deposition. Some studies have indicated that in areas downwind of particular point sources, there may indeed be harmful effects on vegetation; effects on human health are more difficult to isolate and much controversy exists on this subject, especially over the potential effects of long-term low level exposure. Although sulphur dioxide can contribute to an acid rain problem, the effects of SO_2 emissions themselves tend to be seen over a much shorter distance (short range transport) than the effects of acid rain due to long range transport, a phenomenon which is discussed in this report. It must be recognized, however, that these are two separate environmental issues, one of which (i.e., long range transport) is unlikely to be a problem in the foreseeable future in Alberta, while the other (short range transport) raises some concerns now.

2.

The Hydrologic Cycle

In recent years, the term "recycling" has often been associated with the activities of conscientious groups and individuals who return items such as bottles and newspapers to be reused or transformed into other products. In nature, many substances are constantly being recycled or recirculated among the various components of our global environment: the water, air, soil, and all living organisms. One of these components, that is, water, is itself continually being transformed and recycled as vapor, snow, rain, hail, fog, and so on. This cycle, termed the "hydrologic cycle," is essential to life, and as illustrated in Figure 1, it impinges upon all other components of the global ecosystem. Furthermore, the transformations which can occur during the cycle have significant implications for the ecosystem components which are subsequently involved.

Solar energy and gravity combine to drive the hydrologic cycle. Water is converted to water vapor through evaporation from oceans, lakes, and rivers and as the result of **transpiration** by plants. The water vapor is transported by wind movement, ultimately condensing on solid particles in the atmosphere, then falling as some form of precipitation.

Gaseous carbon dioxide (CO_2) and water (H_20) reach an equilibrium in the atmosphere whereby CO_2 dissociates only slightly to produce carbonic acid (H_2CO_3). This is a mild acid, so that rain or snow under normal atmospheric conditions would, in theory, be expected to have a **pH** of about 5.6 (Likens et al. 1979). Although in terms of the pH scale the value of 5.6 represents an acidic solution, this value is generally considered to be normal for precipitation; that is, representative of "clean" precipitation. However, other substances reaching the atmosphere may shift the pH in either direction. Sea spray in coastal areas and dust particles tend to contribute **basic** characteristics to the precipitation by providing **ions** such as calcium, magnesium, and sodium. On the other hand, gases such as sulphur dioxide (SO_2) and oxides of nitrogen (NO_x) can be oxidized in the atmosphere and converted to sulphuric acid (H_2SO_4) and nitric acid (HNO_3) respectively or to intermediate forms. More recent data now suggest that, in fact, the background pH of rainfall might range from 4.5 to 5.6 due to variability of the natural sulphur cycle alone (Charlson and Rodhe 1982).

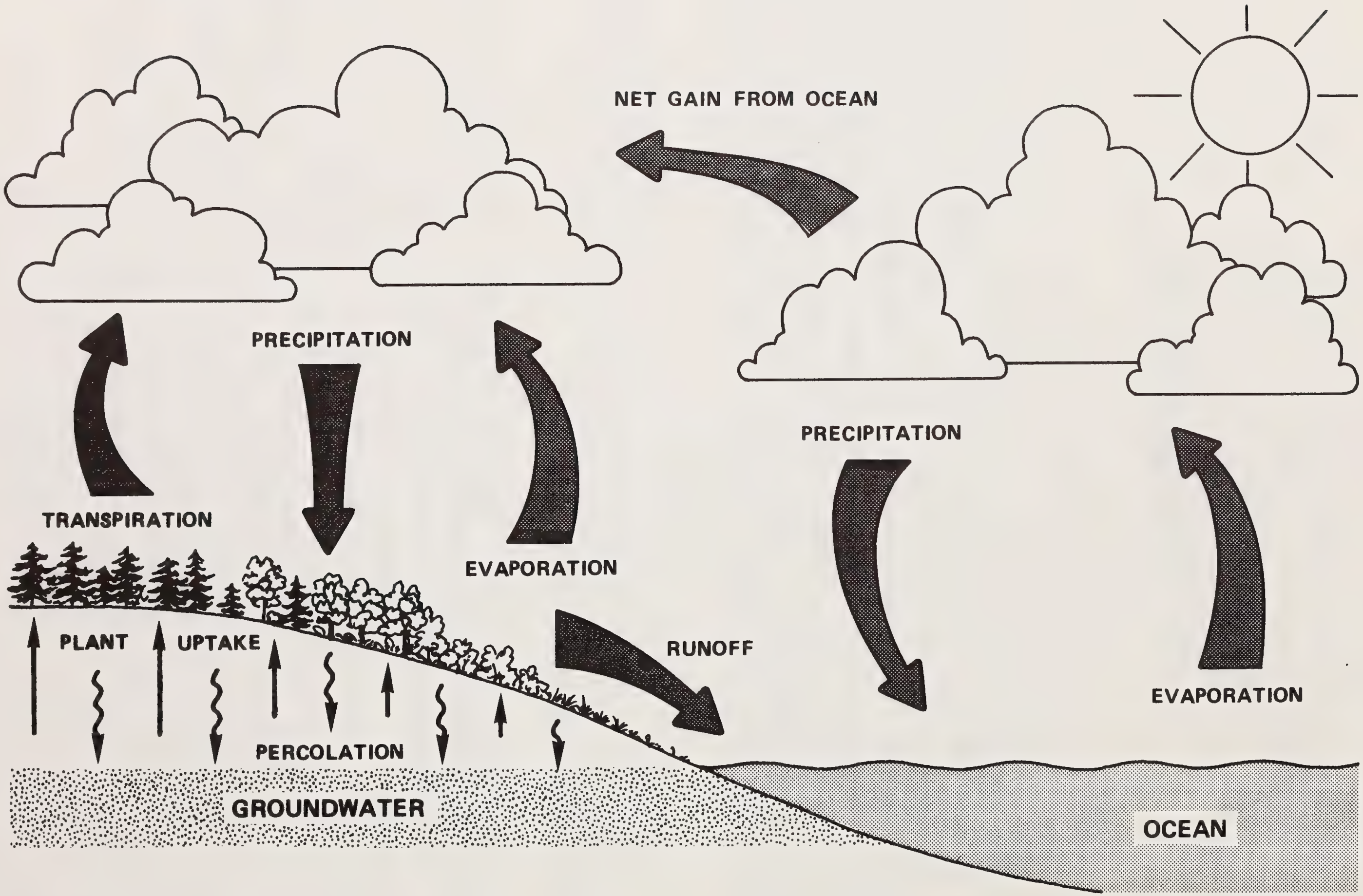


Figure 1. The Hydrologic Cycle

Prior to the Industrial Revolution, volcanoes and other natural sources contributed most of these substances to the atmosphere, and natural, or biogenic, emissions are still responsible for a significant portion of these atmospheric compounds on a global basis. However, in some industrial areas, where the effects of acid deposition are most evident, anthropogenic (that is, resulting from human activity) emissions predominate; in eastern North America, for example, the emissions of SO_2 and NO_x are at least ten times larger from human activities than from natural processes (Acid Rain Peer Review Panel 1983).

The increasing population and technological innovations associated with the Industrial Revolution signified a major turning point in the relationship between human beings and their environment. The connection between industrial emissions and acidic precipitation was enunciated in 1872 by an English chemist named Robert Smith in his book *Air and Rain: The Beginnings of a Chemical Climatology* (Cowling 1982). Twenty years earlier Smith had called attention to the changes in precipitation chemistry as one moved from the middle of a polluted city (Manchester, England in this case) to the surrounding countryside (Cowling 1982). Since then, much work has been done on what is popularly referred to as "acid rain," and Cowling (1982) provides an historical perspective on this topic. Many of these studies have been done in Scandinavia, Canada, and the United States, all of which are experiencing problems due to long range transport and acid deposition. Acid rain is only one aspect of long range transport, however; the next part of this report will examine in detail the long range transport of atmospheric pollutants and the effects of acid deposition.

3.

The Phenomenon of Long Range Transport

Long range transport of atmospheric pollutants (LRTAP) is generally considered to occur when the distance involved exceeds 100 kilometres. Obviously a source of emissions is required, and long range transport is favored when pollutants are emitted at a height sufficient to allow them to enter the wind stream where they can be mixed and widely dispersed. As well, meteorological conditions must be such that the pollutants can be transported for long distances. This transport process is crucial in determining the ultimate effect of the pollutants since the original emissions can be chemically transformed in the atmosphere to other compounds which may do far more environmental damage. Transformations which have received considerable scientific and public scrutiny and which will be the major focus of this report are those involving the acid-forming emissions SO_2 and NO_x. The final factor to consider in assessing the potential environmental effects of long range transport is the vulnerability or sensitivity of the ecosystem upon which the pollutants are finally deposited. If a region has natural protection in the form of high **buffering capacity**, then environmental effects due to acid deposition are likely to be minimal, at least in the short term.

Thus, three general conditions are necessary before environmental problems resulting from LRTAP can occur (Carroll 1982). These conditions are:

1) an emission source (either a collection of sources from a large industrial or urban area, or a very large point source);
2) appropriate meteorological conditions to enable transport and transformation of the emissions;
3) a sensitive receiving region or ecosystem.

CONDITIONS NECESSARY FOR LONG RANGE TRANSPORT

Sources of Air Pollutants

Many atmospheric emissions, whether biogenic or anthropogenic, can undergo long range transport. Among those known are ozone, carbon monoxide, oxides of nitrogen, sulphur dioxide, and various organic gases and particulates. Although biogenic emissions contribute significantly to atmospheric loadings, in this report, as in most of the literature on long range transport, attention will be focussed on anthropogenic emissions; however, once substances are in the atmosphere their fate depends on their physical and chemical characteristics rather than their origin. Of the known anthropogenic acid-forming emissions, sulphur oxides and oxides of nitrogen are of most concern in a discussion of long range transport. Over 90 percent of anthropogenic sulphur emissions are in the form of SO_2. The remaining 10 percent originates as either sulphate (SO_4^{2-}) or sulphur trioxide (SO_3). Sulphates can exist in combination with various **cations**, whereas SO_3 combines readily with water vapor to form sulphuric acid aerosol (H_2SO_4), or particulate sulphuric acid (Barnes 1979). Although the atmospheric chemistry of NO_x is not well understood, it is known that nitric oxide (NO) and nitrogen dioxide (NO_2) also react with atmospheric water, albeit at a slower rate than SO_2. The mechanisms and implications of these transformations will be discussed in the next section of this report.

Major sources of SO_2 in Canada are the smelting of non-ferrous ores (mainly copper and nickel) and the burning and refining of fossil fuels containing sulphur. Current Canadian emissions of SO_2 are about 4.8 million tonnes per year, 80 percent of which are emitted east of the Manitoba-Saskatchewan border (Work Group 3B 1982). The single largest contributor is the smelting industry with more than 40 percent of total SO_2 emissions originating from non-ferrous smelters in Manitoba, Ontario, and Quebec (Choquette and Vena 1982).

In the U.S., coal-fired electrical generating plants are the major contributor, producing nearly 16 million tonnes of SO_2 per year, or more than two-thirds of all U.S. sulphur dioxide emissions (Work Group 3B 1982).

The amount of SO_2 emissions depends, among other things, on the sulphur content of the ore being smelted or the coal being burned. Sulphur is naturally associated with copper and nickel deposits, and is a by-product of the smelting process. Coal deposits vary in their sulphur content from 1 percent or less, to more than 5 percent. When large amounts of coal are burned, emissions from even low-sulphur coal can be substantial.

Whereas most SO_2 emissions come from large stationary sources, about 45 percent of NO_x emissions originate with the transportation sector, mainly gasoline-powered motor vehicles (Choquette and Vena 1982). Any form of fossil fuel combustion generates oxides of nitrogen, so that power plants and heating processes are also significant producers. In addition to their properties as acid-forming emissions, nitrogen oxides are precursors to the formation of ozone and other photochemical oxidants which contribute to the smog problems characteristic of the Los Angeles area and increasingly experienced in parts of southern Ontario and Quebec (Choquette and Vena 1982). Total North American NO_x emissions have been estimated at about 21 million tonnes with the U.S. accounting for 92 percent and Canada for 8 percent (Work Group 3B 1982).

Currently in eastern North America, about 66 percent of the precipitation acidity is the result of SO_2 emissions (which form sulphuric acid) and the remainder is due to NO_x emissions (which form nitric acid) (Choquette and Vena 1982). However, the contribution of sulphate to acid precipitation is apparently leveling off, as SO_2 emission control strategies are improved and implemented; thus it is anticipated that NO_x emissions, which have so far proved more difficult to control, will account for an increasing proportion of the acidity in precipitation (Babich et al. 1980).

One of the control strategies which has been effective in improving the quality of local ambient air is the use of higher stacks. The average height at which gases are injected into the atmosphere has increased by nearly three times in the last century (Committee on the Atmosphere and the Biosphere 1981). Although air quality is usually improved in the immediate vicinity of the source, taller stacks emit gases into the wind stream where they may be transported for hundreds of kilometres. During this time, emissions can be chemically transformed and ultimately deposited far from their source. Although many scientific data seem to support the link between upper atmospheric emissions and tall stacks (particularly those on smelters and coal-fired plants) and acid deposition downwind, in some cases it can be difficult to pinpoint an actual source and thus assign responsibility or blame. Furthermore, the seasonal aspect of high emission rates has changed, as coal has been used less for winter heating and more to generate electricity for air conditioning, resulting in heavier year-round emissions.

The next section of this report will consider some of the atmospheric conditions necessary for long range transport and the chemical transformations which occur during this time.

Transport, Transformation, and Deposition of Acid-Forming Emissions

Transport Emissions whose atmospheric lifetime exceeds several hours may be transported considerable distances through the atmosphere. Residence times and chemical pathways are partially determined by the physical state, particle size, and chemical reactivity of the emissions. Generally, the properties conducive to short atmospheric lifetimes are large particle size and high reactivity and solubility (Committee on the Atmosphere and the Biosphere 1981). Other factors which affect residence time in the atmosphere include the height of injection of emissions and the occurrence and type of precipitation. For example, even intense emissions will be quickly removed from the atmosphere on a rainy day and long range transport will not occur (Barnes 1979).

Two meteorological conditions which are of particular interest with regard to long range transport are the stagnating summertime high pressure areas such as those which occur over eastern North America and western Europe, and prolonged periods of persistent brisk winds (Altshuller and McBean 1979). In the first case, emissions from diverse sources can accumulate, become well mixed by daytime convection, and be transported away from the high pressure centres to affect areas hundreds of kilometres across for several days at a time (Committee on the Atmosphere and the Biosphere 1981). Strong winds, in the second case, reduce plume rise and reaction time and tend to remove emissions from source areas. The meteorological conditions promoting LRTAP span a range of weather types and some of these are considered in more detail by Barnes (1979) and others (Stern 1976; Smith and Hunt 1978).

Transformation As acid-forming emissions are transported aloft, they can be chemically transformed via several processes. Due to the abundance and high reactivity of atmospheric oxygen, most elements will tend to form oxides of various sorts (Committee on the Atmosphere and the Biosphere 1981).

Conversion of SO_2 to SO_4^{2-} (and ultimately to H_2SO_4) in the atmosphere can occur as a result of two major types of oxidation reactions. Homogeneous oxidation of SO_2 typically occurs in polluted atmospheres (that is, in the presence of a variety of other chemical species) and involves gas-phase collision with strong oxidizing radicals. This pathway depends on a number of factors, foremost among them, the generation of free radicals through **photochemical** processes. The second type of reaction involves both gaseous and liquid or solid phases, and is termed "heterogeneous oxidation." Oxidation rates for homogeneous reactions range from 0.1 percent to 10 percent per hour, but rates for heterogeneous oxidations are unknown (GCA Corporation 1981).

> *The relative magnitudes of the contribution of gas-phase and aqueous-phase formation of* H_2SO_4 *vary as a function of season. At southern latitudes for all seasons it is likely that the gas-phase photo-oxidation pathway is important. At northern latitudes for all seasons, it is likely that the aqueous phase* SO_2 *oxidation pathway (wet particles, fogs, clouds, precipitation) is important, and in the winter is dominant (Work Group 2 1982:4-13).*

Overall, summer climatic conditions of higher temperatures and humidity may lead to more efficient oxidation of SO_2 to H_2SO_4 (Committee on the Atmosphere and the Biosphere 1981).

Formation of nitric acid (HNO_3) from NO_x involves a series of complicated reactions with several stages of oxidation before nitrates are produced. Because of the complexity of these chemical processes and the variety of factors which control them, estimated rates of conversion of NO_x to nitrates range from hours to days (GCA Corporation 1981).

More detailed information on the photochemistry and pathways of oxidation can be obtained from references in the reading list at the end of this report.

The conversion of oxides of sulphur and nitrogen (gaseous forms) to the more stable sulphate and nitrate aerosols (particulate forms) increases their atmospheric lifetime, facilitates transport, and contributes to the regional nature of the acid rain problem (GCA Corporation 1981). The residence time of sulphur compounds in the atmosphere is typically between one and five days in industrialized parts of the world, such as eastern North America (Altshuller and McBean 1979).

Nitrogen oxides, on the other hand, are only effectively removed after further oxidation, and because this is a complex and more prolonged chemical process, the atmospheric lifetime of nitrogen compounds is generally considered to be greater than that of sulphur compounds (Barnes 1979).

Deposition Although pollutants can be removed from the atmosphere and deposited at the earth's surface through a variety of processes, all can be classified as either "wet" or "dry" deposition. Both gases and particulates can be involved in both types of deposition.

Removal of pollutants via precipitation (wet deposition) occurs as a result of either rainout or washout processes. Rainout processes occur in clouds and begin with the condensation of water vapor on particles termed "cloud condensation nuclei." These nuclei can be small dust particles, gas molecule clusters, or pollutant particles such as sulphate aerosols. Various pollutants can be dissolved in the droplets, which can subsequently grow to form precipitation-sized particles. If atmospheric conditions are appropriate, these droplets then fall as rain or snow. During a precipitation event, washout may also occur as pollutants below the cloud are scavenged by falling rain or snow. Due to the dynamic nature of clouds, pollutants can be cycled through the aqueous phase many times before being deposited on the ground by precipitation (GCA Corporation 1981).

Wet deposition is an important pathway for the gases SO_2, NH_3, and HNO_3, and for particulate SO_4^{2-} (Work Group 2 1982). Hydrogen ions are associated with sulphates and nitrates in precipitation, so that the deposition is itself acidic. Acid deposition effects have been termed "episodic" or "cumulative." Episodes involve large acid depositions in a short period of time and episodic effects are usually short term. However, cumulative effects result in the accumulation of deposited material over a long period of time, although each individual deposition may have been slight (Galloway 1978). The potential for acidification of the receptor area depends on its sensitivity; ecosystem sensitivity will be discussed later in this report. One factor which influences the effectiveness of wet deposition is the ease with which materials are incorporated into precipitation elements. The main wet deposition pathways for sulphur are through droplet formation around sulphate aerosols and SO_2 being incorporated into droplets and oxidized to SO_4^{2-}. HNO_3 is also sufficiently soluble to be taken up by cloud and rain drops (Work Group 2 1982). A second factor influencing wet deposition is the "precipitation regime," derived from such factors as frequency of precipitation, type of storm, and relative contributions of rain and snow to the total precipitation (Work Group 2 1982). Topography can affect wet deposition on a localized basis, as **orographic precipitation** makes a significant contribution to pollutant loading in regions such as southern Norway (Ottar 1976).

Dry deposition is used to describe all other atmospheric removal processes, including **absorption** or **adsorption** of gaseous pollutants by vegetation, soil, water, masonry, and so on (Urone and Schroeder 1978). Dry deposition is a more continual process, and can contribute significantly to ambient pollution, especially when the emissions include relatively heavy particles. An example of heavy particles would be the trace metals which are often emitted from smelters or fertilizer plants). Dry deposition is an important removal pathway for the gases SO_2, HNO_3, and NH_3 and possibly for the particulates SO_4^{2-} and NO_3^- (Work Group 2 1982), although it should be noted that the gases are not themselves acidic; chemical or biological reactions are required at the receiving area to release hydrogen ions and create acidic conditions. Depending on the sensitivity of the receptor area, such reactions may or may not occur. The effectiveness of a particular dry deposition process or pathway is governed by many factors, including the chemical and physical properties of the substances, ambient atmospheric conditions, and properties of the receiving surface.

Attempts to calculate the relative importance of wet and dry deposition processes have been complicated by knowledge gaps in the field of atmospheric chemistry and by the inadequacies of available techniques for measuring deposition, particularly dry deposition. Some of these problems will be considered later in this report.

Ecosystem Sensitivity

The third factor which must be considered in assessing the potential environmental implications of LRTAP is the sensitivity or vulnerability of the receiving ecosystem. Although high concentrations of SO_2 can injure vegetation and/or soils, such effects typically occur within tens of kilometres of the emission source and are not considered to result from long range transport. The same can also be said of heavy metal particles emitted from sources such as smelters. In this case, it can be difficult to distinguish the effects due to heavy metal pollution from those due to increased acidity; indeed there may be **synergistic** effects uncharacteristic of either problem by itself. Both of these aspects have been considered in the scientific literature, and will not be discussed here. The discussion of "ecosystem sensitivity" in this section and "effects" in the next section will be in relation to acid deposition.

A quotation from Work Group 1 in the U.S.—Canada Memorandum of Intent on Transboundary Air Pollution (1983:16) provides a good general statement on sensitivity assessment:

> *Regions which may be sensitive to acidic deposition have one or more components (i.e., forests, aquatic life, soil, or water) susceptible to degradation under the influence of acidic deposition. Relative sensitivity of these components is reflected in the rate at which an ecosystem component degrades under a particular acidic deposition loading. Different underlying criteria have to be used to represent sensitivity for the different ecosystem components, such as rate of tree growth, characterization of the soil-base status, or water alkalinity. Because so little is known about the acidic deposition dose-response relationships, the underlying*

> *criteria are often imprecise. Therefore, relative sensitivity can only be approximately represented or mapped, and then perhaps for only a few species, ecosystems, or theoretical effects.*

Although "no overall ecological 'terrestrial sensitivity' scheme for evaluation of acid rain impacts yet exists" (Cowell et al. 1981:4), some general observations can be made. Ultimately the sensitivity of a region depends on its capacity to neutralize wet acid deposition or to prevent dry deposition from reacting to produce acid. A sensitive or vulnerable region does not have the buffering capacity to do this, resulting in an accumulation of free hydrogen ions, and eventually an increase in acidity (decreased pH).

> *In general terms, areas with surficial material comprised of calcareous marine or glacial lake deposits can be considered to have low sensitivity to acid precipitation. Acids in the precipitation should be well buffered by these deposits (Rubec 1981:5).*

Limestone-bearing rock formations have an almost infinite capacity to neutralize the levels of acidity expected from acid fallout (Bormann 1982). The presence of such formations has significance for both terrestrial and aquatic ecosystems. In typical calcium carbonate or calcium silicate-bearing soils or rocks, a normal weathering process produces waters having calcium and bicarbonate as the major ionic components. Such conditions not only give rise to soils capable of neutralizing acid input but runoff from these areas also provides lakes and streams with increased buffering capacity.

Areas underlain by rocks resistant to weathering and having shallow non-calcareous soils (such as much of the Precambrian Shield) tend to have low buffering capacity, as fewer neutralizing ions are available. When the input of hydrogen ions (H^+) exceeds the levels of available exchangeable cations (such as calcium and magnesium), other less available more harmful cations are leached (such as aluminum, iron, zinc, and manganese) with potentially toxic effects on the ecosystem. In some cases, H^+ inputs exceed the ability of soils to fix hydrogen ions and the excess is exported to surface waters (Work Group 1 1983).

Various approaches have been taken to assess region sensitivity to acid deposition. Most of these have focussed on measurement of various physical and chemical properties of soil and underlying material. However, other factors also affect sensitivity to acid deposition; among these are types and genetic make-up of organisms in the ecosystem, amount and timing of precipitation, and the topography of the receiving region. More details on these factors and the development of sensitivity criteria can be obtained from the bibliography and the reading list at the end of the report.

The vulnerability of agricultural land to acid deposition is difficult to assess, since the addition of nitrogen fertilizers can lower soil pH much faster than acid deposition can. Thus acidity development in sensitive soils is more likely if nitrogen fertilizers are applied at a high rate (Coote et al. 1982). Furthermore, in areas which have acidic soils lime is commonly applied to farmland as a standard agricultural practice to maintain desired soil pH, and lime will ameliorate acidic conditions regardless of their cause.

EFFECTS OF ACID DEPOSITION ON SENSITIVE ECOSYSTEMS

The environmental impact of air pollutants results from their interaction with ecosystem components and not from their presence in the atmosphere itself (Altshuller and McBean 1979). Furthermore, many pollutants can interact with and be influenced by other pollutants, as well as by elements normally present in the air, water, and soil; thus the effect of any given pollutant may be hard to isolate. Sometimes the effects are indirect; for example, aluminum and many heavy metals such as nickel, lead, and copper are more soluble at low pH, so their concentration (and thus their toxic effect) increases as they are **mobilized.** When direct interactions enhance the effects of one or both pollutants, the relationship between them is termed ''synergism'' — the result is more than additive. When interactions mitigate harmful effects, a relationship is termed "antagonism "(Committee on the Atmosphere and the Biosphere 1981).

Both the cationic and **anionic** components of acid precipitation molecules can have an impact on ecosystems. Oxides of nitrogen are a good example, since their contribution to acid precipitation may supply both an essential and limiting nutrient, nitrogen, and a potential toxicant, hydrogen ions, to receiving ecosystems. In the short term, the nutrient contribution is likely to be more important, while the acidifying component may have more significance in the long term (Committee on the Atmosphere and the Biosphere 1981). However, the contribution of hydrogen ions (that is, the component which alters acidity) has been better studied and is generally considered to have more serious effects.

Effects on Terrestrial Ecosystems

According to Babich et al. (1980), acid precipitation may meet three possible fates, depending on the specific properties of the receiving ecosystem.

1) The hydrogen ions may be neutralized by alkaline salts, such as calcium carbonate.
2) The hydrogen ions may exchange with other cations already present on soil organic matter.
3) The acid precipitation may leach through the soil and enter ground or drainage water.

Soil type, then, plays a major role in determining the vulnerability of an area to acid deposition, and chemical changes which occur in soil can ultimately influence both vegetation and nearby surface waters. **Cation exchange capacity,** considered in the second point above, is one of the criteria often used in assessing soil sensitivity to acid deposition. Two important aspects are associated with soil cation exchange. When hydrogen ions exchange with soil cations which are essential for plant growth (such as calcium, magnesium, potassium, and sodium) the latter are leached out of the soil, and may cause a loss of fertility and productivity. Then, as hydrogen ions accumulate and the pH decreases, toxic heavy metal cations in the soil become soluble, while other essential elements such as phosphorus become insoluble and thus unavailable to plants. Increased soil acidity can also alter the balance of soil microbial communities, often favoring fungal pathogens which are more tolerant of low pH than bacteria and many soil invertebrates. In turn, such a shift in soil biota tends to reduce decomposition rates and the associated release and cycling of plant nutrients (McFee 1978).

As exchange sites in the soil become saturated with H^+, acidic soils in fact become less susceptible to further acidification by acid precipitation. At this point, substantial amounts of acid run off to surface waters or percolate to groundwaters, which then suffer a pronounced decline in pH (Committee on the Atmosphere and the Biosphere 1981).

Direct effects of acid deposition on vegetation are difficult to study in the field. Simulated acid rain with a pH of less than 3 has produced various symptoms on plant foliage but sensitivity of individual plants varies with the developmental stage and the species. The variety of potential effects to vegetation includes damage to protective surface structures such as **cuticle,** interference with reproductive processes, disturbance of normal cell metabolism, and alteration of host-parasite interactions (Cowling 1978). Furthermore, synergistic effects of acid rain and other pollutants may also be damaging vegetation, adding to the complexity of the problem.

Temperate forest ecosystems are important not only in terms of their size and productivity, but also in terms of their economic value. However, because trees at this latitude grow so slowly, they can be affected by a variety of stresses during their lifetime. It thus becomes very difficult to isolate the effects of acid precipitation on tree growth from those effects due to climatic variation, water deficits, attacks by pests, and other stresses. Generally, coniferous forests are more vulnerable to acid precipitation than hardwood forests; herbaceous vegetation is more vulnerable than woody vegetation; and plants in regions of high rainfall are more vulnerable than desert plants (Cowling 1978). Furthermore, there is now some evidence to suggest that acid fog may be also be making a significant contribution to the decline of some trees at high elevations in the northeastern U.S. (Hileman 1983). Because acid soils do not recover, even after the deposition has ceased, potential damage to forests represents a significant threat. As yet there are no practical methods to ameliorate acidic conditions once they have developed in forest soils.

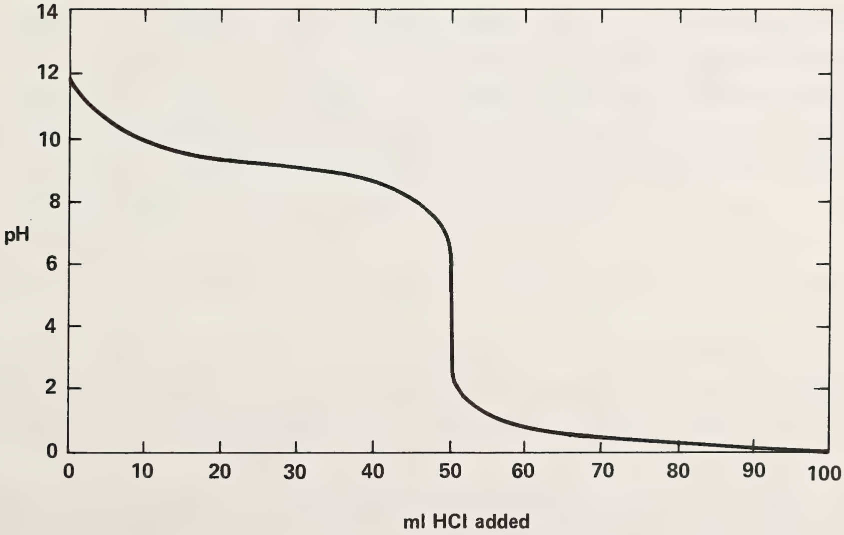
Direct effects of acid deposition on terrestrial wildlife have not been documented and are considered unlikely. However, indirect effects have been postulated through three possible mechanisms (Work Group 1 1983):

1) contamination of browse by heavy metals mobilized as a result of increased acidity,
2) reduction in nutritional value of browse or food source,
3) loss of browse species or impairment of habitat.

Effects on Aquatic Ecosystems

Much of the data on impacts of acidic precipitation has been obtained by studies on aquatic organisms and freshwater ecosystems. Thus the manner and severity of disruption resulting from acidification of the affected ecosystem can be postulated with more confidence than for terrestrial systems (GCA Corporation 1981). As with terrestrial ecosystems, the sensitivity of aquatic systems is determined by the buffering capacity. Studies indicate that the ability of a lake and a drainage basin to neutralize inputs of acidic precipitation is largely predicated by the bedrock composition of the watershed (GCA Corporation 1981). For example, lakes situated in an area of non-calcareous granite bedrock normally have a poor buffering capacity and are vulnerable to acidification. The buffering capacity, and thus the rate of acidification, varies from lake to lake. The chemical principle of such acidification is illustrated by the **titration** curve in Figure 2. Although the acid (HCl) and base (NH_3) used in this example are not typical of lake chemistry, the

Figure 2. Titration of a Weak Base (NH_3) with a Strong Acid (HCl)



Source: Masterton and Slowinski, 1977

figure illustrates that between certain pH values (in this case between 8 and 10) a given system has buffering capacity and is slow to respond to addition of acid. In a natural environment, a lake with some buffering capacity may be able to absorb inputs of acid with very little change in pH and apparently no damage to the ecosystem. However, if additions of acid continue, the system reaches a point where it is no longer buffered and the pH declines sharply; in the figure, this point is reached after the addition of 50 ml of hydrochloric acid. It is difficult to determine in a lake how much buffering capacity remains (or conversely, how much more acid can be neutralized). The lack of this critical information is often exploited by opponents of emissions controls, who maintain that long-term measurements in lakes said to be receiving acid precipitation show no measurable increase in acidity.

The rate of change of water quality of lakes experiencing acidification is still not well understood. Nevertheless, there is evidence that both short term pH depressions following snowmelt and storm runoff and long term cumulative acid loadings are affecting aquatic biota in sensitive lakes and streams. In eastern North America sulphuric acid has been identified as the dominant component contributing to the long term surface water acidification process; nitric acid contributes to pH depression of surface water during periods of snowmelt and heavy rain runoff in some areas (Work Group 1 1983). Significant contributions in this area of research have been made by scientists working in the Experimental Lakes Area of northwestern Ontario (Schindler 1980).

Hydrogen ions deposited in snow tend to be stripped from snow crystals early in the spring snowmelt process, and much of the total annual H^+ export from a watershed occurs during a brief spring period (Work Group 1 1983). This can be significant in areas which receive large amounts of snow. The effects of such an "acid pulse" can be devastating, particularly to many amphibians which breed in temporary pools created by snowmelt and spring rains. Even organisms in larger bodies of water can be affected by this shock, as it occurs at the time when eggs are hatching, and the young are often more vulnerable to a lowered pH. Continued juvenile mortality will have a long term impact on the population, ultimately contributing to its decline and possible disappearance.

Long term cumulative effects of acid deposition can produce major shifts in species composition and structure of the aquatic ecosystem. The number and diversity of species tend to decline as pH drops. Fish mortality from acidification has been more thoroughly studied than any other aspect of this process; fish tolerance to low pH varies with species, age, and size, and with physical factors such as season and water temperature (GCA Corporation 1981). Prolonged exposure to acidic conditions can lead to reproductive failure and **morphological aberrations** in some species. As with terrestrial ecosystems, a lowered pH tends to mobilize toxic metals (such as mercury, copper, nickel, and lead) and it can be difficult to separate the influence of acidity from that of metal toxicity (Gorham 1976). Although an accumulation of such metals in fish may not be fatal, it can have implications for humans or predators eating the contaminated fish. Aluminum, however, is one metal which has been implicated in fish mortality at low pH levels. It is known to irritate fish gills, causing the gills to produce a protective mucus coating which erodes the gill filaments and leads to suffocation (Hileman 1981).

Although increased acidification affects organisms at all levels in the aquatic ecosystem, it is difficult to determine whether the effects are direct or indirect. The primary producers in the aquatic food chains, the phytoplankton, are sensitive to acidification, and when the pH of the water body falls below 6, both biomass and species diversity decline (Babich et al. 1980). The decline of such organisms disrupts the energy flow in affected ecosystems by limiting food supply for organisms higher up the food chain. Furthermore, since acid tolerance of organisms varies, the disappearance of less tolerant species can lead to a proliferation of tolerant organisms, and predator-prey and host-parasite relationships are altered.

Finally, a lower pH enhances the growth of fungi and other **acidophilic** organisms such as *Sphagnum,* which tend to take over the lake bottoms. Bacterial populations decline, slowing decomposition rates and thus reducing nutrient cycling and productivity.

Attempts to mitigate the effects of acid deposition on aquatic ecosystems have centred around the addition of neutralizing agents such as lime (Driscoll et al. 1982). Liming of aquatic systems must, however, be done with considerable caution, and with an awareness that the ecosystem will not be restored to its original pre-acidic state even though the pH of the water may have returned to more normal levels. Impurities in the limestone can create additional problems and stresses, and the long term effects on aquatic biota have yet to be established.

OTHER EFFECTS

Anthropogenic emissions and the compounds which they form have other effects in addition to those just described. Some of these will be discussed only briefly in this report. More details can be obtained from references in the reading list and in the bibliography.

Haze layers arising from the long range transport of sulphate aerosols are common downwind of large industrial areas. Not only can these layers reduce visibility but the aerosols can interfere with the atmosphere's heat balance either directly by absorbing and scattering radiation or indirectly by modifying the microstructure of clouds (Barrie et al. 1976). Suspended particles intercept solar radiation to reduce the amount reaching the ground, and they also intercept terrestrial radiation which enhances the so-called "greenhouse effect."

The rate of deterioration of architectural structures has increased at an alarming rate in industrial countries due to NO_x and SO_2 emissions. Furthermore, deterioration of structures in areas distant from emission sources suggests that long range transport is a contributing factor. The essential components (that is, carbonate and silicate minerals) of common building materials (natural stone, concrete, and mortar), are exposed and susceptible to attack by acid precipitation, leading to weathering and eventual disintegration of the structure (Gauri 1980).

Evidence of direct effects of acid precipitation on human health is lacking, but the potential exists for an indirect impact through consuming fish or drinking water containing high levels of metals leached from soil or pipes.

Precursors of acid precipitation, particularly sulphur dioxide and sulphate aerosols, may cause respiratory problems in susceptible individuals, such as asthmatics or those prone to other bronchial ailments. Once again, it is difficult to isolate the effects of these particular air pollutants from those of other atmospheric components and from those which are caused by individuals themselves, especially through smoking. Considerable uncertainty still remains about the effects of such long-term exposure to low levels of SO_2. A discussion of these aspects is outside the scope of this report, but some references are included in the reading list.

ALBERTA'S POSITION

In western Canada various circumstances have combined to produce a situation which is somewhat less bleak than that of the central and eastern provinces with regard to acid deposition. Scientific opinion seems to be that at the present time, there is not a problem here with long range transport of air pollutants (Technical Committee for the Long Range Transport of Atmospheric Pollutants in Western Canada 1981). There are, however, two other important aspects which this statement indirectly addresses: firstly, is there potential for future environmental problems due to acid deposition, and secondly, is there now a problem with local transport of air pollutants? The answers seem to be "yes" in the first case and "maybe" in the second case. This section will examine Alberta's position and discuss why there currently does not seem to be a problem with long range transport. Following sections will briefly consider the potential for future problems in Alberta and neighboring jurisdictions, and also the impact of local transport of air pollutants within Alberta.

Emissions

Alberta is presently the largest producer of acid-forming emissions (that is, total SO_2 and NO_x) in western Canada. This situation is unlikely to change as long as supplies of fossil fuels remain to be tapped. Extensive deposits of oil, natural gas, and coal are located in Alberta; although many of these deposits have a relatively low sulphur content, processing and transportation of large quantities of natural gas, and combustion processes in general release substantial amounts of both sulphur and nitrogen oxides into the atmosphere. As shown in Table 1, total industrial SO_2 emissions in Alberta in 1981 were about 560,000 tonnes (Alberta Environment 1982); of the 4.8 million tonnes emitted annually in Canada, this represents almost 12 percent.*

Overall levels of air pollution in western Canada are low compared to eastern Canada due to the presence of fewer large industrial sources (see Table 2). In the west, ore processing in Manitoba and oil and gas processing in Alberta are the major sources of SO_2 emissions. The natural gas processing industry is by far the leading source of sulphur emissions in Alberta, followed by oil sands plants, and then a variety of industries, all with significant but much lower total sulphur gas

Table 1. Observed Sulphur Emission from Industrial Sources Operating in Alberta in 1981*

Source	Daily	Annual^{+}	Annual $SO_2$$^{++}$ Emissions	% of Total
Extraction Gas Plants	341.6 (46)**	124,684	249,368	44.6
Oil Sands Plants	193.6 (2)	70,664	141,328	25.3
Power Plants	136.1 (4)	49,676.5	99,353	17.8
Sour Oil Production Facilities	41 –	14,965	29,930	5.3
Flaring Gas Plants	18.9 (46)	6,898.5	13,797	2.5
Fertilizer Plants	9.6 (5)	3,504	7,008	1.3
Refineries	8.8 (5)	3,212	6,424	1.2
Pulp and Paper Plants	8.1 (2)	2,956.5	5,913	1.1
Heavy Oil Recovery Plants	3.9 (2)	1,423.5	2,847	0.5
Other	5.1 (2)	1,861.5	3,723	0.7
Total	766.7 (114)	279,845.5	559,691	100.3

Adapted from Alberta Environment (1982).

*All amounts in tonnes.
**Figures in parentheses are the number of plants contributing daily output.
$^{+}$Annual emissions represent daily emissions x 365.
$^{++}$Values for SO_2 emissions were obtained by doubling the values for annual S emissions in the preceding column (as per Sandhu et al. 1980).

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*Emissions data are often expressed as weight of sulphur emitted, most of which is in the form of SO_2. Because the two oxygen atoms in a molecule of SO_2 have approximately the same atomic weight as one sulphur atom, a generally accepted method of converting amounts of sulphur emitted to SO_2 is to multiply S emissions by 2.

Table 2. Annual Emissions of Sulphur Dioxide and Nitrogen Oxides in Canada in 1978*

Province	SO_2	NO_x	Total Acid-forming Emissions
Newfoundland	58.4	30.5	88.9
Prince Edward Island	5.7	6.8	12.5
Nova Scotia	187.0	85.1	272.1
New Brunswick	170.0	59.5	229.5
Quebec	1,119.4	331.7	1,451.1
Ontario	1,614.5	531.5	2,146.0
Manitoba	499.6	79.8	579.4
Saskatchewan	56.7	148.6	205.3
Alberta	526.4	377.7	904.1
British Columbia	236.0	172.5	408.5
N.W.T. and Yukon	2.7	26.3	29.0
Total	4,476.4	1,850.0	6,326.4

Source: Environment Canada. Air Pollution Control Directorate (1983).

*All amounts in thousands of tonnes.

emissions (such as power plants, sour oil production facilities, and refineries) (Sandhu et al. 1980). Most of the sulphur is emitted as SO_2, but the term "sulphurgas emissions" includes small amounts of other compounds such as hydrogen sulphide (H_2S) and carbon disulphide (CS_2).

Total sulphur emissions in Alberta have remained relatively stable, and well below the licenced levels of emissions for several years. However, further development in the oil sands area could lead to large increases in sulphur emissions. As shown in Table 1, the two oil sands plants now in operation accounted for 25 percent of the total sulphur emission in Alberta in 1981, while the 92 gas processing plants produced 47 percent of the total. It is very difficult to predict the potential impact of oil sands development because so much uncertainty exists about the eventual number of plants and the technology which will be available when and if these plants come on stream. Much of the sulphur resulting from oil sands development is in the coke which is produced from these operations, and which if burned, would result in high sulphur emissions. Research is under way to find uses for the coke, most of which is now being stockpiled.

Processing and combustion of fossil fuels also give rise to large amounts of NO_x emissions, as shown in Table 3. In 1978, fuel combustion processes in mobile and stationary sources accounted for more than 94 percent of the total NO_x emissions.

Table 3. Annual Emissions of Nitrogen Oxides* in Alberta in 1978.

Source	Emissions (tonnes)		% of Total
Industrial Processes		20,060	5.3
Petroleum refining	777		
Tar sands operations	13,653		
Nitric acid production	4,712		
Other	918		
Fuel Combustion/Stationary Sources		175,686	46.5
Power generation by utilities	35,764		
Industrial fuel combustion	130,054		
Other	9,868		
Transportation		181,034	47.9
Solid waste incineration		153	negligible
Miscellaneous		754	0.2
Total		377,687	99.9

Source: Environment Canada. Air Pollution Control Directorate (1983).

*expressed as NO_2.

Effluent from gas processing plants with sulphur recovery units tends to be "relatively 'clean' in the sense that the only pollutant emitted is SO_2 without a significant loading of particulates or other contaminants" (Rowe 1976:321). In the absence of other, neutralizing particulates such as those emitted from a coal-burning power plant, a smelter, or an oil sands coke burning power plant, the potential may be greater for these emissions to have acidifying effects on soil and water (Rowe 1976).

Meteorological Conditions

As indicated previously, several atmospheric and meteorological conditions are necessary before LRTAP can occur. Acid-forming emissions must be transported, transformed, and deposited in a vulnerable area in order for there to be a problem due to long range transport. In most cases, acidification as a result of long range transport occurs in the form of wet deposition, although this is not thought to be the case in Alberta.

In Alberta, winds range predominantly from the northwest through to south (Shewchuk et al. 1981). This is especially significant for the existing point sources in the oil sands area of northeastern Alberta, since a portion of the sensitive Precambrian Shield lies downwind. Some technical studies have been done on stack plume dispersal and various models have been proposed to describe plume behaviour (Sandhu et al. 1980). One factor complicating the study of plume dispersal, particularly from gas plants, is that many of these plants are located in the foothills region. Turbulence levels increase over irregular and complex terrain and investigations of medium and long range transport under these conditions have not been undertaken.

Some work on the atmospheric transformation of acid-forming emissions has been done in Alberta, but much of this is in the area of computer simulations and modelling, based on limited collected data. A large portion of this research has been sponsored by the Alberta Oil Sands Environmental Research Program (AOSERP). AOSERP was set up in 1975 in an agreement between the governments of Canada and Alberta to study environmental issues associated with oil sands development. Field studies in the oil sands area suggest that homogeneous gas phase oxidation of SO_2 is an important transformation mechanism (MacDonald et al. 1982). These data suggest that under Alberta conditions the average lifetime of SO_2 is only a few days during typical summer conditions but may be a number of months during winter conditions.

Deposition

Because Alberta's climate is fairly dry, the amount of dry deposition is thought to greatly exceed the amount of wet deposition. In northern Alberta and Saskatchewan, summer months contribute nearly half of the annual precipitation, with winter snowfall representing 30 to 40 percent of the total; mean annual precipitation for this area is about one half of that of southern Ontario and Quebec where snowfall is normally less than 30 percent of the total (Shewchuk et al. 1981). Thus although snowfall makes a significant contribution to total precipitation in the prairies, because snow is a poor scavenger of atmospheric compounds (Summers and Hitchon 1973) it does not add very much to the acid input. Nevertheless, more research into the relationship between snow and air pollution is needed; such studies should also consider the atmospheric chemistry of air pollutants under the winter conditions experienced in Alberta. Studies sponsored by AOSERP (Barrie and Walmsley 1978; Barrie and Kovalick 1980) concluded that over 98 percent of the winter-time emissions of oxides of sulphur and nitrogen released by the Suncor power plant were carried beyond 25 kilometres; in addition, the long atmospheric lifetime of these emissions in the winter suggests that they might well be widely dispersed before acidic aerosols could be formed.

Dust particles present in the air can act to neutralize potentially acidic precipitation. This occurs across much of the prairies where terrestrial natural dust containing carbonate and other minerals interacts with raindrops to enhance the buffering chemicals in the precipitation. Such a reaction is evident in various places on the prairies where the pH of rainfall is actually greater than the value of 5.6 which is characteristic of "normal" rain. Both the federal and provincial governments have programs in place to monitor precipitation in Alberta. There are five stations which are part of CANSAP (Canadian Network for Sampling Precipitation) and six stations operated by Alberta Environment. Samples tend to exhibit a pH between 6 and 7.5, although lower values have been recorded near Edmonton and Calgary (Sandhu et al. 1980); these lower values may possibly be related to heavier NO_x emissions characteristic of urban areas. Klemm and Gray (1982) observed that in central Alberta less than 20 percent of precipitation data revealed pH values lower than 5 and none were less than 4. They did, however, conclude that the concentrations of sulphate and nitrate were generally large enough that acid rain would be produced if at least part of the potential acidity was not neutralized by basic species, such as those containing calcium and ammonium ions.

Studies by Nyborg et al. (1977) seem to confirm that dry deposition is more important in Alberta. They concluded that the amount of sulphur in dry fallout is often greater than ten times the amount in wet fallout in non-forested areas. However, the fate of such sulphur (which may be adsorbed as gaseous SO_2 or be deposited as particulate S) depends on several factors; foremost among these are the buffering capacity of the soil and the rate of sulphur deposition. In areas which are close to and downwind of emission sources, environmental damage may be primarily due to the effects of the gas or particles rather than to increased acidity.

Measurements of actual deposition have been complicated by technical problems with equipment design and available chemical methods. Unforeseen complications in data interpretation can also arise, such as those reported by Barrie and Sirois (1982); in this case in southern and central Alberta there were errors in concentrations of H^+, NH_4^+, SO_4^{2-}, and NO_3^- ions associated with contamination by calcium and magnesium compounds. Improper selection of sampling sites, equipment failures, and insufficient replication are some of the problems faced by researchers, and different approaches make it very difficult to compare results.

Despite some disagreement on the amount and form of acid deposition in Alberta, sulphur and acid loadings are clearly much lower than those in eastern North America. Dry deposition is the major contributor in Alberta, and this phenomenon results mainly from local or short range transport rather than from long range atmospheric transport and transformation. Although research has been conducted in various locations on plants and soils, it is considered that

> *...there is not sufficient scientific evidence either to substantiate or refute the possibility that cumulative subtle effects of sulphur emissions may result in long term reduction in soil and vegetation productivity (Sandhu et al. 1980:33).*

Ecosystem Sensitivity

Ecosystems which are least sensitive to acidification have the ability to neutralize wet deposition, or prevent chemical and biological reactions from occurring in the soil to form acids from dry deposition, or both. Acid precipitation (that is, precipitation which has a pH less than 5.6) occurs on about 5 percent of the province of Alberta (Rubec 1981); nearly all of this impinged area is well buffered and not considered to be sensitive to acid precipitation.

The task of identifying potentially sensitive areas on the prairies is complicated by the expanse of land devoted to agriculture. Some soils in the Peace River region and in central Alberta are naturally acidic, and anthropogenic SO_2 emissions could have a negative impact by altering the chemistry and nutrient status of these soils. Excluding the Peace River region of Alberta and British Columbia, where 31 percent of the soils are acid, Alberta has 1.4 million hectares (3.5 million acres) of acid soils and another 2.3 million hectares (5.7 million acres) which are potentially acid;* overall, Alberta has 70 percent of the acid soils in western Canada (Hoyt et al. 1981). More agricultural soils are becoming acidic, but most of this is due to use of chemical fertilizers, especially those high in nitrogen or sulphur (Hoyt et al. 1981). Some crops, such as alfalfa and barley, are sensitive to lowered soil pH, and increased acidification could result in significant crop reduction.

Some sulphur-deficient soils also exist in Alberta but atmospheric emissions cannot be counted on to alleviate such deficiencies due to variability in timing, location, and amounts of deposition. Appropriate reactions must also take place in the soil to convert the sulphur to a form which plants can use.

> *From an environmental viewpoint, it is the time of year as well as the concentration, duration, and frequency with which sulphur gas emissions enter the atmosphere that are the main emission factors determining the environmental consequences upon the terrestrial ecosystem, and not simply the total sulphur gas emissions emitted per year (Legge and Bogner 1982:452).*

Hoyt et al. (1981) tentatively projected that industrial sources could cause 48,000 hectares (110,560 acres) to become acid over a 15-year period in Alberta. This is a rather small amount compared with their further projection that the use of nitrogen fertilizer will be responsible for an increase of about 1 million hectares (2.5 million acres) of acid soil in Alberta and the Peace River region of British Columbia by 1985; by then, 25 percent of the soils in Alberta and more than 40 percent of the soils in the Peace River area will be acid.

Table 4 provides an indication of the relative importance of acid deposition and fertilizer in causing soil acidity across Canada. In eastern and central Canada not only is the total acidity problem more severe, but the atmospheric contribution is much more important than in the western provinces.

Studies of the effects on forest vegetation in Alberta have focussed more on local emissions and deposition of SO_2 than on acid deposition resulting from long range transport. Effects of SO_2 are normally seen less than 100 kilometres downwind of emission sources and thus cannot be considered to result from long range transport. Considering the location of Alberta's forests with regard to emission sources and prevailing winds, it is unlikely that damage is occurring to forests or forest soils from LRTAP.

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* Acid soils are those with a pH less than 6.0, and potentially acid soils have a pH between 6.1 and 6.5.

Although data on aquatic effects are limited, one study of lakes in northeast Alberta concluded that alkalinities were high and the lakes were considered to be highly resistant to pH change (Hesslein 1979). Even those lakes on the western edge of the Precambrian Shield are considered to be sufficiently buffered (Shewchuk et al. 1981).

Some concern has been expressed in Saskatchewan about the effects of future oil sands development in northeast Alberta since a large portion of the downwind area lies on the Precambrian Shield. As well, studies indicate that more than 400,000 hectares of land in Saskatchewan are

Table 4. Representative Annual Contribution to Soil Acidity by Atmospheric Deposition (1977-1979) and Fertilizer Use (1974-1979)

	$CaCO_3$ equivalents required annually for neutralization (kg/ha)		
Location	Atmospheric*	Fertilizer**	Total
Atlantic Provinces	30	84	114
Quebec	35	51	86
Ontario	33	90	123
Manitoba	5	72	77
Saskatchewan	0	12	12
Alberta	2	51	53
British Columbia	5	66	71

* Based on estimated contribution of long-range transported acidity from precipitation calculated from Coote et al., 1981.

** Based on fertilizer sales data, Canadian Fertilizer Institute, assuming an average requirement at a ratio of 3:1 (calcium carbonate to nitrogen).

Source: W. Simpson-Lewis et al. (1983).

naturally acidic to some degree (*Canadian Environmental Control Newsletter* 1982). Nearly one-third of the land in Saskatchewan now receives mildly acidified precipitation, and about two-thirds of these impingment areas are in the north. This region extends into the southern portion of the District of MacKenzie, Northwest Territories, which is also considered to be potentially sensitive (Rubec 1981). pH measurements of Saskatchewan's shield lakes indicate that they are now neither very acid nor very alkaline; however, many of these lakes are both shallow and poorly buffered, so that should acid precipitation become a regular event, these lakes must be considered vulnerable (Liaw 1982). Indeed, this situation epitomizes one aspect which has made the long range transport problem such a difficult one — the transboundary nature of air pollution.

4.

Jurisdictional Aspects of Transboundary Pollution

Like water, air is a fluid medium; however, the movement of air and atmospheric components is less well understood and certainly more difficult to control than the movement of water. The unenclosed nature of the atmosphere and the movement of air across political boundaries is a major obstacle to the implementation of successful air pollution control strategies. Because such strategies rely on co-operation from emitting industries, which are ultimately regulated by government, it is necessary to look at transboundary jurisdictional problems in the context of political units (that is, states, provinces, and nations).

In the case of long range transport, the areas of emission origin and deposition are frequently not within the same political boundaries. (This, of course, depends on the size of the jurisdiction and the responsibility of the various levels of government.) In Europe, for example, the environmentally sensitive and less industrialized countries of Scandinavia are downwind of heavily industrialized regions such as Germany and the United Kingdom. Indeed, it is estimated that more than 56 percent of the sulphur deposition in Norway and Sweden comes from other countries (Rosencranz 1980). Policies regulating emitting industries are determined by their national governments, upon which receiving countries have no direct influence.

Similar atmospheric sulphur budgets have been developed for eastern North America. In eastern Canada, the two major inputs of sulphur to the atmosphere are local anthropogenic emissions and transboundary flow from the U.S., and these are approximately equal in magnitude (each is about 45 percent of the total). On the other hand, approximately 90 percent of the atmospheric sulphur inputs in the eastern U.S. originate within the country and only 4.5 percent come from Canada (Galloway and Whelpdale 1980). In absolute terms, eastern Canada is receiving three to four times more sulphur dioxide (and about 11 times more oxides of nitrogen) emissions than are being exported annually (Altshuller and McBean 1979).

One factor which has increased the incidence of LRTAP was the implementation in the early 1970s of strategies to control local air pollution in the U.S. To minimize local ground-level effects, methods that dispersed pollutants upward and outward (and so contributed to long range transport) were encouraged. This meant the construction of stacks which are now taller and more prevalent than when the Clean Air Act was actually passed in 1967 (Carroll 1982). Canada has fewer tall stacks, but the 1,250 foot INCO stack in Sudbury is the single largest point source of SO_2 emissions in the world.

Industry, government, and the scientific community must all be involved in solving the long range transport problem. There is also a role for, and an impact on, society as a whole since emission control strategies (or the lack of them) can affect investors, workers, consumers, tourists, landowners, and so on. Again because of the distances involved in long range transport, costs to control emissions are often incurred in one jurisdiction to provide benefits elsewhere. Costs to reduce emissions can be high, depending on the abatement technique chosen. Scrubbers, for example, are very costly to install and operate even in a new plant; retrofitting is even more expensive, and unfortunately it is many of the older plants which produce the highest sulphur emissions. If forced to adopt such technologies the utility companies and other industries would logically pass on such costs to consumers. Switching to low-sulphur coal might be cheaper in terms of capital costs, but this could have ramifications for those companies and workers who mine coal with a higher sulphur content. All of these groups would incur costs in some form if stricter emission controls were required.

On the other hand, regions which are being affected by acid deposition have suffered losses and will continue to do so as long as emissions are not reduced. Industries such as fishing and tourism which depend on the use or harvesting of natural resources are particularly vulnerable. Decline in the quality of lakes and streams due to increased acidity has had a severe impact on the tourist industry in some regions of eastern Canada. Despite some controversies, there is evidence that acid-forming emissions and acid deposition are also reducing forest productivity.

Costs to reduce emissions can be fairly easily documented, but the benefits are often less tangible and less easily quantified. Nevertheless the core of Canadian public support for reduced emissions stems from environmental concerns (Carroll 1982). Public awareness in Canada has heightened in recent years and more pressure has been brought to bear on politicians to come up with diplomatic solutions to the transboundary problem. Within Canada, the Ontario government has issued provincial control orders to reduce SO_2 emissions in Ontario, and agreements have been reached with Ontario Hydro and INCO to enact long term emission reduction programs; these have not been entirely successful to date. The federal government has passed Bill C-51, amending the Clean Air Act, thus providing the same legislative protection to the U.S. as that provided to Canada by Section 115 of the U.S. Clean Air Act. Bill C-51 provides

> *...the governor in council, on the advice of the Minister of the Environment, with discretionary authority to regulate individual emission sources or classes of*

> *sources which cause or contribute to air pollution, which, in his opinion, is endangering or may be anticipated to endanger the health, safety, or welfare of persons in another country (Roberts 1980).*

The Economic Council of Canada (1981) has recommended that the federal government further amend the Clean Air Act to give it the authority to regulate the sources of air contaminants that cross provincial boundaries. Although this sounds like an admirable approach, political and legal considerations would make it extremely difficult to enact such legislation. Other logistical problems such as monitoring and enforcement could create further difficulties. One of the major problems at the international level has been the burden of proof; that is, the inability to identify specific emitters responsible for emissions that undergo long range transport. If transboundary fluxes are low and areas downwind are well buffered, should all emitting industries still be expected to install expensive abatement technology? Generally speaking, costs for point source emitters to recover emissions rise disproportionately to the amount recovered, as the amount approaches 100 percent; for example, it may cost half again as much to recover 98 percent of the SO_2 emitted as to recover 96 percent. However, when dealing with plants which may be emitting 50 tonnes of SO_2 per day even with 95 percent or more recovery, an additional recovery of 1 to 2 percent can make a big difference in total sulphur loading. In areas such as Alberta where emissions are spread over the entire gas processing industry, use of appropriate technology on the largest emitters while spreading the cost over all emitters could be one way of keeping individual costs down while still effecting significant emissions control. Implementation of similar programs has been tried in some situations in the U.S., with variable results depending on the number of emitters involved, among other things. Disposal or sale of recovered products is another aspect which must also be considered. In Alberta, the recovery and marketing of sulphur, which is a by-product in the processing of natural gas, is an important industry. Sulphur sales of approximately 7.8 million tonnes, at an average price of about 85 dollars per tonne, represented a return to producers of more than 600 million dollars in 1982 (*Oilweek* 1983).

In situations where multiple sources exist, and the relative contributions of atmospheric loadings are difficult to determine, compensation can be provided to damaged areas through a fund to which polluters contribute (Rosencranz 1980). Although similar funds already exist in some countries to deal with various environmental damages on a national level (Rosencranz 1980), such an approach assumes that the value of aesthetic environmental resources can be quantified and it also assumes that pollution is acceptable as long as the polluter pays.

With regard to LRTAP across the Canada/U.S. border, there has been some activity in the area of scientific exchanges and consultation. In 1978, a Bilateral Research Consultation Group was set up, and they have produced two reports (Altshuller and McBean 1979, 1980). A Memorandum of Intent on Transboundary Air Pollution was signed by the U.S. and Canada in 1980, and final reports of the technical working groups were released early in 1983. There were, however, unreconcilable differences in data interpretations and recommendations between the two countries. Co-operation in gathering of data is nevertheless continuing. Basic differences in government attitude have been responsible for some of these bilateral difficulties. Canada seems to be on a course of increasing government regulation, while the prevailing American attitude is one of deregulation and less government involvement. The Economic Council of Canada (1981) has suggested that while relaxation of regulatory restrictions would often benefit Canadians, stringent regulations should nevertheless be considered in the case of common-property resources such as air and water.

The United Nations Conference on the Human Environment in 1972 commented on the responsibility of states for extraterritorial damages caused by pollution (Rosencranz 1980), and in Europe there was concern about acid precipitation at least a decade before it became a high profile environmental issue in North America. Various organizations and councils in Europe have attempted to reach multilateral agreements governing LRTAP; however, these too have been restricted to promoting international consultation and co-operation. Existing international laws do not effectively foster preventive action, and

> *...accepted notions of international law cannot alone compel major modifications in the pollution control policies of industrialized nations . . . . International legal principles do not yet describe the point at which a nation's interest in industrial development must yield to concerns surrounding the effects of transfrontier pollution. Moreover, there is no mechanism yet for enforcement of any international legal doctrines. No international agency is empowered to give force to international environmental principles not incorporated into binding agreements (Rosencranz 1980:17).*

A knowledgeable public which continues to exert pressure on government is probably the best way to get action on this problem. Although gaps still do exist in the scientific literature about the phenomenon of LRTAP, a great deal is already known about the effects of acid deposition. Unfortunately, some of these gaps are permanent because appropriate data were not collected years ago, before the significance of such information was known. However, governments and industry must acknowledge that damage from acid deposition and long range transport is occurring, and direct research funding toward innovative solutions. Areas such as western Canada which may not presently have problems of long range transport and acid deposition could still benefit from such solutions. There is potential for acidification in regions downwind of Alberta and there is some evidence (as discussed in the next section) to suggest that short range transport may be affecting some areas of Alberta now.

5.

Short Range Transport in Alberta

Transport of sulphur emissions over short distances in Alberta has been studied from several points of view. A number of investigations of gas plant plume dispersion have been published; these deal mainly with interrelationships of meteorology and plume behavior at distances of approximately 10 kilometres downwind of the source (Sandhu et al. 1980). Similar studies have also been undertaken in the oil sands area.

However, concern and controversy are probably greatest about the effects of industrial sulphur emissions on soils, vegetation, and human health. Over relatively short distances (less than 100 kilometres from a source) sulphur emissions generally do not have sufficient time to be transformed to sulphate aerosols; consequently, it is often SO_2 gases themselves which damage vegetation and which are adsorbed directly by soils.

Sulphur dioxide is known to reduce plant productivity.

> *The most impressive evidence for* SO_2 *suppression of forest growth stems from investigations carried out in natural forest environments exposed to elevated ambient* SO_2 *from surrounding point sources (Smith 1981:298).*

Vegetation injury from SO_2 can be classed as acute or chronic. Acute injury results from the absorption of high concentrations of SO_2 in a short time while chronic injury is caused by long-term absorption of sub-lethal concentrations of SO_2. Acute injury is easier to identify as the symptoms are clearer and can usually be related to an episodic emission. Chronic injury, on the other hand, is more subtle, and continuing exposure can result in secondary effects such as reduced growth rate and increased sensitivity to other environmental stresses such as frost, drought, and plant pests or disease (Knabe 1976).

In fact, one study has found that exposure of balsam fir trees to SO_2 can cause increased foliar emission of a group of compounds which are attractive to spruce budworm moths (Renwick and Potter 1981). Host/pathogen interactions represent a sensitive indicator of plant stress, since the changes in balance between host and parasite may reveal a subtle **abiotic** stress long before the response would be detectable in the healthy plant alone (Shriner 1980).

Other early indicators of air-pollutant stress include sensitive plants, especially **epiphytic** lichens and **bryophytes.** Two characteristics make these epiphytic organisms susceptible to air pollution and therefore good bio-indicators: first, their occupation of an elevated ecological niche makes them more exposed to airborne contaminants, and second, they lack the waxy cuticle which provides protection for many other plant species. Studies in Alberta have disclosed a variety of epiphytic species which respond to SO_2 concentrations lower than those which produce visible symptoms in higher plants. These studies are listed in the literature review compiled by Sandhu et al. (1980).

One factor which further complicates investigations of this nature is the occurrence of synergism. The effects of SO_2 emissions on vegetation may change depending on what other compounds are also present. Synergistic effects have been observed when SO_2 interacts with NO_2 or ozone or heavy metals (Knabe 1976), but plant species respond differently to different combinations and effects of individual components can be hard to isolate or reproduce in the laboratory.

Studies such as that by Legge et al. (1976) suggest that vegetation around gas plants with high (but allowable) emissions can be affected but the extent and mechanisms are difficult to determine. Furthermore, the zones of deposition (the area over which deposition occurs) and impingement (the area over which effects are evident) may not be the same; deposition often occurs over a larger area than impingement, so that not only must researchers assess damage to vegetation, they must attempt to determine the concentrations responsible. Among the plants sensitive to SO_2 fumigation are balsam poplar, trembling aspen, white birch, wild rose, saskatoon, and fireweed, all common plants in Alberta (Hocking 1975). Sulphur is accumulated in plant tissue, and a study by Legge and Rogner (1982) in the Whitecourt area indicated that this process in the coniferous species which they studied could provide an excellent indication of exposure of the forest ecosystem to sulphur gas emissions.

Effects of SO_2 on soils generally relate to whether or not adsorbed SO_2 is converted to sulphate and then to sulphuric acid. Studies have attempted to assess the impact of sulphur emissions on soils by looking at adsorption in potted and field soils, bare and covered soils, forested and agricultural soils, and under wet and dry conditions, and various techniques have been used to measure sulphur concentration and uptake (Sandhu et al. 1980). However, as indicated previously, the variety in methodology and data interpretation makes comparisons difficult and usually unwarranted. Studies in the same emissions area have reached conflicting conclusions, and there is often no acknowledgement of the natural variability in soil pH among samples or regions.

Effects of particulate sulphur blown onto fields or vegetation from stockpiles or during transit can be severe, but tend to be on a very localized basis and reclamation is usually possible.

Effects of sulphur emissions on human health have probably generated more controversy in Alberta than any other aspect. Again the potential for problems immediately downwind of emission sources exists, but researchers have had difficulty linking health problems with emissions.

Many factors are involved, such as age, smoking habits, diet, respiratory condition, and the presence of other airborne materials, and the task of assessing the effects of sulphur emissions is not an easy one. Many residents downwind of gas plants suspect that a positive correlation exists between health problems and downwind status, but direct links are very difficult to establish. Emissions of hydrogen sulphide (H_2S) are also toxic to humans, but exposure to H_2S tends to be uncommon. Accidents such as the gas well blowout near Lodgepole in late 1982 can expose large numbers of people to hydrogen sulphide, but the effects remain to be documented and assessed. Although H_2S has a more offensive odor than SO_2, it is in fact much less toxic (Sax 1979). It is also interesting to note that the ambient air standard in Alberta for SO_2 is 150 ug/m^3 for a 24-hour period, while that for the less toxic but more offensive H_2S is only 4 ug/m^3 (Franson et al. 1982). A discussion of sulphur emissions and human health is outside the scope of this report, but some references are offered in the reading list and Sandhu et al. (1980) also list some pertinent studies.

6.

The Role of Research

MONITORING AND ASSESSMENT

Most of the research on long range transport in North America has been done in the eastern half of the continent, since this is where the situation has been most critical. Consequently the inventory of sensitive areas is more complete and the precipitation monitoring networks are more extensive in central and eastern Canada. As mentioned previously, the CANSAP and Alberta Environment programs for precipitation monitoring include 11 locations in Alberta, but there have been technical problems in some places and data have been misleading (Barrie and Sirois 1982). Some monitoring work has also been carried out by private consulting firms under contract to various industries (McKinnon, Allen 1983).

There is a need for studies to determine the distribution and sensitivity of both soils and water to acidification. Such studies would provide baseline data so that changes could be assessed accurately and reliably, and these studies would also be valuable in predicting potential effects of industrial development. Such a study was done on soils in the Sand River area of Alberta, and the methodology might also be appropriate for other regions in the province (Holowaychuk and Lindsay 1982). Because there have been so many different techniques used in previous soil studies, making results difficult to compare, suitable standardized procedures would be very valuable for future research projects. Thorough studies of the LRTAP phenomenon require extensive knowledge in many areas of science, with the result that detailed comprehensive research programs can be difficult to co-ordinate, finance, and carry out. A comprehensive joint study by the provincial government and the petroleum industry into the environmental effects of acid deposition in Alberta was recently announced, and is expected to take seven years to complete. This would seem to provide an excellent opportunity for the co-ordination of research and data collection suggested earlier. Given the complexity, the political sensitivities, and the very controversial nature of this subject, it is of the utmost importance that acid deposition and long range transport studies be designed, performed, and interpreted with great care and integrity so that the conclusions will be widely accepted in both scientific and government communities.

Many biological systems naturally receive acid deposition and are not harmed. However, when these amounts surpass the level which a particular ecosystem can safely tolerate, environmental damage may occur. This added burden of emissions and the resulting acid deposition can tip the balance, pushing deposition amounts beyond the tolerance level. For this reason, improved control technology for anthropogenic emissions should be adopted as it becomes available, since with few exceptions, acidified ecosystems cannot be restored to their pre-acidic state.

FORECASTING EMISSIONS AND DEVELOPMENT

Making predictions of any type is a difficult task, often with controversial results. Various approaches can be taken, and the influencing factors assigned different weights in an attempt to produce a realistic forecast. Future emissions of sulphur dioxide in Alberta will be influenced by many factors, among them economic and political conditions for industrial growth and development, available emission control technology, legislation affecting emissions, and demand for the products. Colley and Poon (1982) analysed SO_2 emissions from Alberta sources and presented emissions forecasts to the year 2000, based on two projected provincial growth scenarios. They also considered the application of various levels of technology to emissions control and sulphur recovery, and provided a basis for updating the forecast to allow review and modification of emission management strategies. Their forecast indicates that SO_2 emissions will rise during the 1980s but that by 2000 emissions need not exceed those typical of the period between 1974 and 1981.

These authors are now preparing a similar report for nitrogen oxide emissions in Alberta. Significant NO_x emissions originate from the transportation sector, from gas processing and transporting activities, and from coal-burning facilities. Technology for reducing SO_2 emissions rarely works to limit NO_x, and the relative importance of nitrogen oxides to the acid precipitation problem is expected to increase.

MODELLING

The development and refinement of long range transport models have occurred rapidly in recent years. Such a model might be defined as:

> *...any method that can be used to relate the ambient concentration or deposition rate of a pollutant in a region of interest with the emission rate of the pollutant and its precursors from all the contributing upwind source areas (Altshuller and McBean 1980:6).*

The use of computers in these simulations has meant that large amounts of data can be entered; nevertheless, the atmospheric transport and transformation processes are so complex that models must be simplistic representations of actual events. However, Holling (1980) has shown that models of this type can be very effective.

Models do allow interpolation of data so that gaps between monitored observation points can be filled in. Computer simulations can also be used to determine the relative contribution of a variety of sources to a particular receiving area. There are, however, still some limitations on LRT model applications; one of these relates to the lack of available data to test the models, a problem which should be overcome as monitoring networks are improved and expanded.

ABATEMENT TECHNOLOGY

Carroll (1982) categorizes the technologies to reduce SO_2 emissions into three stages:

1) precombustion, in which sulphur is removed before the fuel is burned through techniques such as coal cleaning, coal gasification, and desulphurization of liquid fuels;
2) combustion, in which sulphur is removed during combustion via processes such as fluidized bed combustion;
3) postcombustion, in which emissions are reduced after combustion by stack or flue gas desulphurization or scrubbers. Some techniques such as coal washing and the use of scrubbers are already being practised, while others such as fluidized bed combustion are still being developed.

Reduction of NO_x emissions requires a different approach from those used to reduce SO_2 emissions. NO_x formation is promoted by high temperatures, among other things, so that application of specific hardware (such as scrubbers) is not usually an appropriate technique. Changes in stationary source operating procedures such as reducing furnace load, closely matching air input to burning needs, and reducing combustion temperatures can result in lower NO_x emission (GCA Corporation 1981). However, combinations of such techniques are usually required, and success at recovering emissions can also vary with the fuel being used. A variety of techniques to control NO_x emissions have been tried in North America and Japan on varying scales and with varying degrees of success (Yaverbaum 1979). Although some research has been successful on a small scale, large scale practical technology such as exists for control of SO_2 remains to be developed.

> *NO_x control technology is still evolving and its development is influenced primarily by environmental regulations proposed in the United States (Zelensky 1982:75).*

The goal of NO_x control strategies is to either convert oxidized forms of nitrogen (such as NO_2) to molecular nitrogen (N_2) or to prevent the oxidation of nitrogen altogether; Carroll (1982) and Zelensky (1982) consider briefly some of the more promising approaches.

As control techniques are refined, there is some concern that emissions such as fly ash which act to neutralize acid-forming emissions will be eliminated, resulting in purer emissions of SO_2. On the other hand, the lack of particulates might reduce the rate of oxidation of SO_2 to SO_3, thus reducing the ultimate amount and strength of atmospheric acid. This aspect requires further investigation to assess the role of various emission components and their fates under the climatic conditions typical of Alberta.

7.

Conclusion

Long range transport is clearly an environmental issue which has far-reaching effects. Not only is a very large area affected by acid deposition, there are frequently economic, medical, and social, as well as environmental ramifications. Environmental damage resulting from long range transport and acid deposition can indirectly cause the loss of jobs in industries such as tourism, fishing, and forestry which depend on healthy ecosystems. Decline of such activities in a community can have further social repercussions, particularly in regions which do not have a diverse economic base. On the other hand, imposition of stringent emission controls could affect the livelihood of other people, for example, those who mine high-sulphur coal or utility customers who might be forced to pay for abatement technology through higher rates.

Despite its far-reaching effects, public awareness of "acid rain" is a relatively recent event in North America, and the attention and controversy which have resulted are unparalleled in the history of Canada–U.S. environmental relations. Controversy over scientific studies aside, the whole issue is complicated by the fact that costs and benefits are inequitably distributed between two different political jurisdictions.

Different interest groups have different approaches to solving the problem, and this is reflected in the two major strategies for dealing with acid deposition. One strategy involves the use of mitigation or reclamation; that is, treatment of symptoms in the affected ecosystem regardless of the cause. The second strategy would require a reduction in emissions at the source to prevent or significantly reduce damage to downwind areas. Limiting emissions certainly is more sensible, and represents a responsible long-term approach to dealing with the problem. However, policy making and enforcement are made additionally difficult because implementation of any single control strategy might not be sufficient. Conditions vary among regions and a successful strategy in one place may not work somewhere else. Nevertheless, the Royal Society of Canada in a report to the Canadian government concluded

> *that a reduction in sulphur dioxide emissions is indeed the only way to stop the observed damage to lakes and streams. All other measures are costly local palliatives (Royal Society of Canada 1983:I-20).*

In many respects, the long range transport/acid deposition debate boils down to an energy issue. In North America the desire for energy self-sufficiency has produced a substantial increase in the rate of extracting and processing fossil fuel reserves during the past decade. Amenities such as air conditioning have become common in many homes and offices, increasing the annual load of utility companies, many of which rely on fossil fuels. Expansion of the transportation sector has increased the amount of nitrogen oxides and hydrocarbons in the atmosphere. In sum, increases in the use of fossil fuels have meant increases in the production of acid-forming emissions.

Alternatives to conventional fossil fuels often leave much to be desired too. Hydro power has traditionally been regarded as a clean, efficient source of energy, but many people have expressed concern about the negative effects of dams on vegetation, wildlife, and agriculture and also about the aesthetic and recreational loss of "untamed" rivers. Nuclear energy, once widely considered to be a panacea, is fraught with problems; concern about its reliability and long-term security have led to considerable public distrust and scepticism. Accidents such as the event at Three Mile Island (and more recently at the Pickering plant in Ontario) have reinforced this image of nuclear power, and the extent to which the nuclear industry will take over from conventional energy sources remains to be seen.

The so-called "soft energy paths" (including solar) have made major advances in the last decade, and should no longer be automatically dismissed as non-credible alternatives, particularly in the provision of heat and power. Conservation of energy, regardless of the source, is a key factor in the whole issue, and although changes have been made in materials, machines, and attitudes, improvements are still needed.

More specifically, long range transport is not presently considered to be a problem in Alberta, but the potential does exist. Potential sources of concern are in the oil sands area of northeastern Alberta, upwind of vulnerable areas in Saskatchewan and the Northwest Territories. However, resource extraction in this region has slowed, and the ultimate level and timing of development are difficult to predict. Various government and scientific committees have been established to monitor and assess the situation with regard to emissions, transport, and deposition. Although much of Alberta seems to be geologically insensitive to acid deposition, there are localized areas in the Peace River area and in central Alberta which have naturally acidic soils and should be considered potentially more sensitive.

Short range, or local transport (less than 100 kilometres) has been studied in Alberta for some time; however, the methods used have not been consistent, leading to results which are sometimes contradictory and unreproducible, and often controversial. Despite problems in some Alberta studies, there are data on the harmful effects of SO_2 on vegetation; as well, copious evidence from studies elsewhere has shown the effects of acid deposition on both aquatic and terrestrial ecosystems. Such information should provide a note of caution to the regulators and decision-makers here if environmental protection is to be given a high priority.

Reaching a consensus on issues such as these is extraordinarily difficult, even within a single political jurisdiction such as Alberta. Biological systems often respond slowly to insidious changes, and assuming that no environmental damage is occurring because there is no widespread visible destruction could be very wrong and ultimately very costly. For various reasons

> *...any current scientifically-derived recommendations (to deal with acid precipitation) must be based upon an imperfect, always increasing, body of pertinent data whose quality and completeness can be expected to improve for decades. Recommendations based upon imperfect data run the risk of being in error; recommendations for inaction pending collection of all of the desirable data entail even greater risk of damage (Acid Rain Peer Review Panel 1983:2).*

Various sectors, such as the oil and gas industry, agriculture, tourism, and outdoor enthusiasts are all anxious to protect their interests. Alberta certainly stands to benefit from related research and policy development being carried out elsewhere, and it is to be hoped that integrated studies now being planned in this province will enable sound decisions to be made in the area of environmental protection from acid deposition.

Glossary

abiotic

Referring to all physical and non-living chemical factors which influence living organisms.

absorption

The taking up of a substance in bulk by another substance; for example, the absorption of water by a paper towel.

acidophilic

Refers to an organism that has an affinity for and grows well in an acid environment; literally, "acid-loving."

adsorption

Holding on a surface, as on the surface of a soil particle; as opposed to absorption, the penetration of substances into the bulk of the solid or liquid.

anion

A negatively charged ion.

basic

Having the nature of, or containing a base. In chemistry, a base is a substance which is capable of accepting or receiving hydrogen ions (H^+) from an acid and combining with them in a chemical reaction.

bryophytes (bryophyta)

A small division of the plant kingdom, including mosses, liverworts, and hornworts, characterized by the lack of true roots, stems, and leaves.

buffering capacity

The ability to resist changes in pH when acid (or alkali) is added. The component or chemical which imparts this ability is the buffer.

calcareous

Of or containing calcium, lime, or limestone.

cation

A positively charged ion.

cation exchange capacity

The total amount of exchangeable cations that a soil can absorb. It is expressed in milli equivalent per 100 grams of soil or of other adsorbing materials such as clay.

cuticle

A delicate waxy layer over the outer surface of the epidermis of plants; it protects against water loss and infections.

epiphyte

A non-parasitic plant attached to another plant (or a non-living structure such as a telephone pole) which it uses for support. An epiphyte obtains moisture and nutrients from the air rather than the soil.

ion

An electrically charged atom or group of atoms, the electrical charge of which results when a neutral atom or group of atoms loses or gains one or more electrons during chemical reactions. The loss of electrons results in a positively charged ion (cation) and the gain of electrons results in a negatively charged ion (anion).

mobilize

To put into active use.

morphological aberration

Morphology is the branch of biology that deals with the form and structure of organisms.

An aberration is a deviation from a standard or ordinary type; thus a morphological aberration is an abnormal development in the structure of an organism, which can occur as a result of heredity, environmental stress, or other factors.

orographic precipitation

Precipitation which results from the lifting of moist air over an orographic barrier such as a mountain range.

pH

The pH scale is a means of quantifying acidity. Technically, pH equals the negative $\log_{10}$ of the hydrogen ion concentration of the solution (i.e., $\text{pH} = -\log_{10}[H^+]$). A neutral solution, neither acid nor basic, has a pH of 7.0. Acidic solutions have a pH of less than 7.0, and the more acid the solution, the smaller the pH. The inverse is true for basic solutions (pH greater than 7.0). Since pH is a logarithmic scale, each unit decrease (for example, pH 6.0 to pH 5.0) represents a ten-fold increase in acidity. For example, a pH of 3.0 is 1000 times more acidic than a pH of 6.0. For comparison, vinegar has pH of about 3, the pH of milk is about 6.6 and that of baking soda just over 8.

photochemical reaction

A chemical reaction influenced or initiated by light, particularly ultraviolet light.

radical

In chemistry, a radical is a stable group of atoms found as part of the molecules of a number of compounds, for example, SO_4^{2-}. A free radical is not stable; it is an atom or group of atoms which possesses at least one unpaired electron, and is therefore free to react with other available chemical species. An oxidizing radical is one which is capable of giving up oxygen to another chemical species (for example, ozone, O_3).

synergism

An action where the total effect of two components in a mixture is greater than the sum of their individual effects.

titration

A method of analyzing the composition of a solution by adding known amounts of a standardized solution until a given reaction (color change, precipitation, or conductivity change) is produced.

transpiration

The passage of a gas or liquid (in the form of vapor) through the skin, a membrane or other tissue (for example, a leaf).

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These references are in addition to those cited in the text and included in the bibliography.

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